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# U. S. DEPARTMENT OF AGRICULTURE

FARMERS' BULLETIN No. 1393

## PRINCIPLES OF DAIRY-BARN VENTILATION



**F**RESH AIR is as necessary for livestock as for human beings. It is possible to maintain a comfortable temperature in a well-built dairy barn and yet have appreciable circulation of air. A tightly built barn will be damp and foul unless ventilation is provided. A good ventilation system in a well-built barn will supply fresh air and remove foul air and moisture without causing drafts, and make possible the control of the temperature of the barn. The heat generated by the animals is used to warm the barn and to promote air circulation. In cold climates, if good ventilation and a warm barn are to be secured, it is essential that heat be conserved by proper insulation and the proper proportioning of the size of the barn to the number of animals it is to hold.

This bulletin explains the general principles underlying the ventilation of barns and discusses the systems of barn ventilation in common use.

Much of the success of the ventilation system depends upon the care and judgment of the person in charge of the barn. No system yet devised makes it possible to dispense with personal attention and the exercise of good judgment.

Washington, D. C.

April, 1924

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# PRINCIPLES OF DAIRY-BARN VENTILATION.

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**V**ENTILATION in a barn is the process and practice of keeping a barn supplied with proper air for breathing. It is a continuous process and is accomplished by diluting the air in the barn with fresh air in such quantities as to maintain the desired degree of purity. The foul air escapes from the barn as the fresh air enters.

## THE NEED FOR VENTILATION.

To maintain health, fresh air is as essential for cows, horses, hogs, and other stock as for human beings; ventilation in barns and other buildings in which stock are kept is just as necessary, as a health measure, as in homes, schools, factories, and other buildings in which human beings live or work in more or less close quarters.

The need for ventilation of cow stables is a consequence of the increased demand for clean, wholesome milk at low cost of production which has made it necessary that each cow shall produce as much milk as possible. In order to increase production breeders have developed the high-producing cow and a greater winter production of milk has been sought. Large winter production requires that tightly built shelter for the cows be provided, particularly in the colder sections of the country. Tightly constructed barns are apt to be damp unless ventilation is provided, and the stabling of animals in dark, poorly ventilated, damp barns affects their health and helps to spread tuberculosis among the stock whenever the germs are present. Clean, wholesome milk can be had only from healthy cows. The same principles are involved in the ventilation of barns for other stock, but this bulletin applies these principles only to dairy-barn ventilation.

## THE PURPOSE OF A VENTILATION SYSTEM.

A good ventilation system, if properly installed and operated, will (1) supply without draft the abundance of fresh air necessary to the health and comfort of cows; (2) make possible control of barn temperature; (3) preserve the building and feed stuffs from mold and rot due to excessive moisture and make spontaneous combustion less likely; (4) provide a measure of disease prevention and control.

## WHY FRESH AIR IS REQUIRED.

A dairy cow breathes approximately 116 cubic feet of air per hour, or more than 200 pounds per day. The air contains oxygen, which is necessary for the proper combustion and assimilation of

her food, and a very small amount of carbon dioxide. In respiration, oxygen is taken up and carbon dioxide given off. When air is inhaled, a part of the oxygen it contains is utilized by the body and when it is exhaled it is warmer than when taken into the body and it contains a reduced amount of oxygen and an increased amount of moisture and carbon dioxide absorbed from the body. Owing to the fact that the percentage of carbon dioxide is usually the test of the degree of ventilation, it is frequently assumed that it is a poison. This, however, is not the case. Carbon dioxide should not be confused with carbon monoxide, a gas which often forms when silos are filled or a gas engine is run in a closed room, and which causes many deaths. In 24 hours a cow will exhale from 12 to 18 pounds of moisture and a somewhat smaller amount of carbon dioxide. It will be seen, therefore, that if the cow were quartered in an airtight barn, so that she would be forced to breathe the same air repeatedly, the amount of oxygen in the air would be steadily reduced and its suitability for breathing correspondingly impaired, and the air would soon become warm, moist, and of bad odor.

To avoid this condition the air in the barn must be constantly replaced by fresh outside air, and it was suggested by King<sup>1</sup> that, for the maintenance of satisfactory conditions, 3,600 cubic feet of air per cow per hour should be supplied. In order to permit the entrance of the fresh air an equal amount of used air must be displaced, and in order to do this a circulation must be established. To establish such a circulation is the principal function of a ventilation system.

#### WHY BARN TEMPERATURE SHOULD BE CONTROLLED.

The heat given off by the animals stabled in the barn must be employed to maintain the temperature at a comfortable degree and also as the motive power to produce circulation of the air; hence there must be enough generated to insure adequate circulation of air without lowering the temperature to an uncomfortable degree. It is possible to maintain a comfortable and fairly uniform temperature in a well-built barn and yet have an appreciable circulation of air. Tests have shown that the quantity of milk yield is affected by sudden changes in temperature. Cows tend to give somewhat less milk when the temperature changes suddenly, but the effect is only temporary. Sudden changes in temperature are avoided in barns which have a well-regulated ventilation system. Good circulation, with the consequent dilution of the impurity of the air, is the aim of all systems of ventilation, but in operating the system the comfort of the animals must be considered as well as purity of the air.

#### DAMAGE TO BUILDING AND FEED.

Poor ventilation causes damp or wet barns. In the colder sections of the United States unventilated barns are frequently found in which the roofs and ceilings are dripping wet with condensed moisture, a condition which is the cause of serious losses due to the

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<sup>1</sup> Ventilation for Dwellings, Rural Schools, and Stables by F. H. King.

molding of feed and hay stored in the building. The feeding of moldy hay to dairy cows may cause additional loss.

Excessive moisture on the roof boards and the rafters causes molding and rotting, and instances could be cited in which timbers in new barns, where such a condition was permitted, have completely rotted off in a very few years. Moisture causes rusting of steel equipment, iron pipes, and other metal parts.

Ventilation aids in the prevention of spontaneous combustion in haymows and granaries. Lack of space will not permit a full discussion of this phase of the ventilation problem, which is nevertheless a very important one. The reader will no doubt recall instances in his own experience in which fires have occurred in hay barns, especially in those in which leguminous hays were stored. Usually these fires result in total loss, as facilities for fighting fires are in most cases lacking.

#### PREVENTION OF DISEASE.

While the loss of feed and the destruction of timbers may constitute a large economic loss, the maintenance of the health of dairy animals is of greater importance, because the health of the citizens of this country is greatly dependent upon the consumption of the products of this class of farm animals and the wholesomeness of these products. The effect of poor ventilation is often not apparent until the damage is done. Continued breathing of foul, damp air lowers the vitality of dairy cows and other animals, rendering them susceptible to the attack of disease germs. Lowered vitality is caused primarily by a lack of the oxygen in the air, but the more direct cause may be a weakened or poor constitution, temporary physical depression, fatigue, exposure to cold, poor sanitation, or poisonous gases. Ventilation can not be looked upon as absolute protection against disease, but an abundant supply of fresh air, together with the removal of foul air and excess moisture, is necessary if the animals are to be kept healthy and vigorous. Disease germs introduced into the blood are destroyed by the oxygen carried from the lungs by the red blood corpuscles, hence the importance of supplying, by ventilation, an abundance of oxygen at all times.

Large sums of money are spent annually in combating the inroads made by tuberculosis, the most insidious and destructive disease to which dairy cows are subject, and the annual loss is enormous to the dairy interests and every taxpayer in the country. Every citizen should use all possible means of combating this disease, not only for his own protection but the protection of society at large. Tuberculosis<sup>2</sup> is a preventable disease and great progress has been made in retarding its spread, but it is still a great menace. The prevention of disease is of greater importance than the curing. Prevention, or at least the minimizing of chances, lies to a very great extent in building up the animals' resistance to disease, which means keeping their bodies in a vigorous, active condition. Lowered vitality means lessened resistance to disease.

Ample sunlight is also a potent agent in the prevention as well as the cure of disease. It reduces the vitality of all germs and actually

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<sup>2</sup> Farmers' Bulletin No. 1069, Tuberculosis in Live Stock: Detection, Control, and Eradication.

destroys many kinds. A light, clean stall, well supplied with fresh air and sunlight generally is the first prescription of the veterinarian treating a sick animal.

## FACTORS WHICH AFFECT BARN VENTILATION.

The following factors must be considered in the design and operation of a ventilation system: 1. The difference in temperature of the air inside and outside the barn. 2. The amount of moisture in the air. 3. The wind. 4. The construction of the barn.

### DIFFERENCE IN TEMPERATURE.

The difference in temperature inside and outside the barn is the most important factor in securing proper operation of the system. When air is heated its volume expands and its weight is reduced. This is the reason warm air rises. A rise in temperature of 1° F. will increase the volume of 491 cubic feet of air 1 cubic foot. If by any means the heated air is prevented from expanding, its pressure against the surrounding walls or inclosure will be increased. This is what happens when the air in a barn is warmed: The volume of air in the barn can not increase, as the size of the barn is constant; the result is that the pressure of the air in the barn becomes greater than that of the unconfined outside air, and this difference in pressure tends to force air out of the barn. If openings are present in the roof of the barn and in the side walls of the stable, the warm air, being lighter and under pressure, will flow out of the upper opening, and the cold air from the outside, being heavier, will flow into the barn through the lower opening, thus creating a circulation of air through the barn. If the barn is equipped with a ventilating system, the warm air in the stable will pass up and out through the outtake flues, causing a draft that is affected by the height of the flues, the higher flues having greater draft. As the warmed and expanded air passes out of the stable it is replaced by colder air entering through intakes or other openings. This, in turn, is warmed and passes outward thus setting up a circulation.

The rapidity with which the air changes depends largely upon the difference in the temperatures of the inside and outside air. The greater the difference in temperature, except as the action is influenced by other factors, the more rapid will be the interchange of air. A common difference in temperature between the air in the stable and the outside air is 20° to 22°. This difference, in zero weather, may become as much as 45 or 50 degrees, and sometimes greater than this in a well-insulated barn during extremely cold weather. During mild weather, when doors and windows are generally open, the difference in temperature may be very small.

This, then, is the motive power which moves the air in the stable, and it is of particular importance that the climatic conditions of the locality be studied in order that expected temperatures may be known. The difference between inside and outside temperatures is caused by the heat emanating from the bodies of the animals, and, since this is the only available heat and the quantity limited, it is necessary that it be so conserved that there shall be sufficient to cause ample ventilation and still maintain a comfortable temper-

ature in the barn. In order to conserve this heat, barns must be well insulated and tightly constructed. Insulation which shuts out cold also shuts out air, hence the necessity of ventilation and the inseparability of these two factors.

A small stove would not be expected to heat a large house. For the same reason a barn should not be expected to be warm when it is only partially filled with stock, or when the volume of air to be heated by the animals is too large. Many ventilation systems have been unjustly condemned for this reason. When the number of stock is not sufficient to fill the barn, the space to be heated may be reduced by the erection of a temporary partition or by filling the unoccupied space with hay or straw.

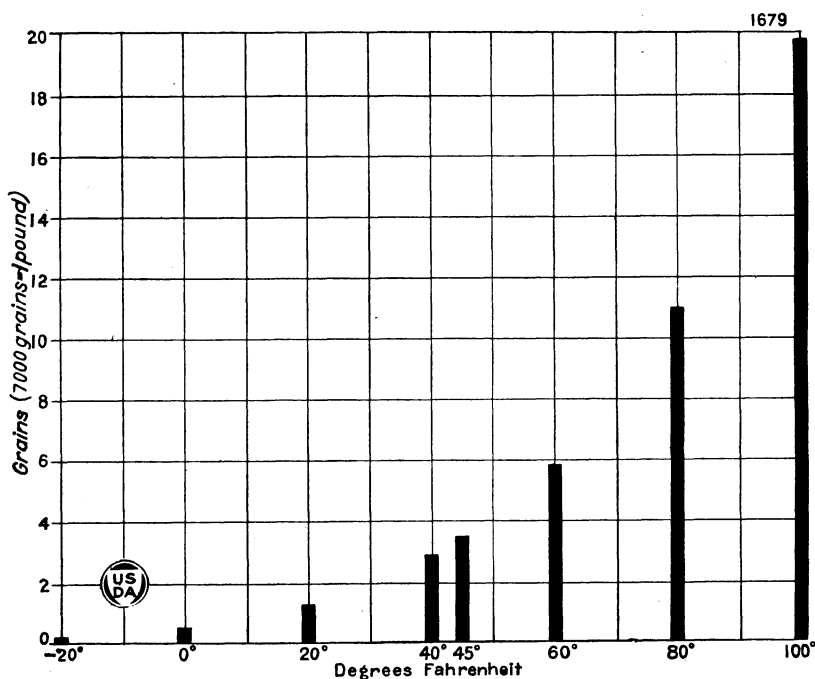


FIG. 1.—Diagram showing the greatest amount of moisture that a cubic foot of air will hold at different temperatures.

#### AMOUNT OF MOISTURE IN THE AIR.

Air contains a varying amount of moisture. The warmer the air the more moisture a given volume will hold. Figure 1 shows the maximum amount of moisture (expressed in grains) that air at different temperatures will hold. At  $-20^{\circ}$  1 cubic foot of saturated air contains 0.166 grain, while at a temperature of  $45^{\circ}$  it will contain 3.414 grains; that is, the absorbing power is more than 20 times greater. The air does not always contain as much moisture as it is capable of absorbing, so the amount it does contain is stated as a percentage of the amount it is capable of holding. This percentage is known as the relative humidity of the air. It is simply the relation between the amount of moisture which the air at a stated tem-

perature contains, and the amount which the air is capable of holding at that temperature. When the air contains as much water as it will hold it is said to be saturated, and the relative humidity is 100 per cent. Relative humidity of 50 per cent means that the air is only half saturated. But whatever amount of moisture there may be in the air, there is some lower temperature at which this amount will be all the air is capable of holding. This temperature is called the dew point because it is the temperature at which the moisture will begin to condense in the form of tiny droplets, or dew.

As shown in Figure 1, air at high temperature is capable of holding larger quantities of moisture in suspension than at low temperatures. As air which contains a certain amount of moisture is cooled, the relative humidity approaches the point of saturation or dew point. Conversely, when cold air containing a certain amount of moisture is warmed, it becomes capable of absorbing more moisture. If cold air is introduced into a barn and warmed by the heat given off by the animals, it has a pronounced drying effect on the air already in the barn and absorbs moisture from materials exposed to it. This explains how the stable air in a well-ventilated barn is capable of absorbing the moisture exhaled by the animals. If the circulation—that is, the continued removal and replacement of stable air—is decreased sufficiently, the air becomes saturated and any decrease in the stable temperature causes condensation of moisture on the walls. It is possible, in factories, to maintain any desired degree of moisture and temperature of the air by the use of heat or refrigeration with proper controlling apparatus. Such control in dairy barns is not practicable, but with properly designed ventilation systems satisfactory results may easily be obtained. Humidity control, then, goes hand in hand with temperature control. The degree of moisture in the air which will produce the most satisfactory results has not yet been determined. In well-constructed barns equipped with a proper ventilation system and filled to capacity, it is possible to maintain the temperature of the stable above freezing even during severe weather and without an undue amount of moisture. Fresh, dry air and a cool stable are better than a warm stable, moist air, and dripping walls and ceiling.

#### EFFECT OF THE WIND.

The wind causes ventilation by pressure on the windward side of the barn, suction on the lee side, and by aspiration or sucking at the top of the ventilators. In most parts of the United States the velocity of the wind during the greater part of the winter does not average over 8 miles per hour, and can not be depended upon to produce ventilation, but the effect of high winds must be guarded against. When the velocity is above 16 miles per hour the effect of the wind upon the ventilation may be rather marked. At this velocity there is pressure on one side of the building and suction on the other. At such times backdrafting of intakes on the lee side is apt to occur. This condition is prevented by the new style of intake valves which close automatically when reverse action of the air currents starts. The tendency to backdrafting in wall intakes is reduced by increasing the length of the ducts.

The aspirating effect of wind blowing across the top of the flue or ventilator head also affects the amount of air withdrawn. There is great variation with respect to this effect, depending upon the design and consequent efficiency of the ventilator head. When the velocity is below 3 miles an hour the suctional effect of the wind upon the ventilator is very small if there is any effect at all. But the wind, whatever its velocity may be, is a form of energy which, coupled with the more important energy in the form of heat from the bodies of the animals, maintains a flow of air through the stable, and with a given amount of energy the volume of air moved and the rate of movement will depend upon the weight of the air circulated and the resistance that must be overcome in its passage through intakes and outtakes.

#### CONSTRUCTION OF THE BARN.

The construction of the barn has a decided effect upon ventilation. If the walls are thin and radiate heat rapidly, the heat lost through them can not be used to cause ventilation. If, on the contrary, the walls are well insulated, the heat is conserved and may be used to raise the temperature of the barn and to cause ventilation.

To maintain a comfortable temperature within the barn it is necessary to depend upon the heat generated by the animals stabled in it. If this heat is allowed to pass outward through openings and cracks or through the materials of which the walls are built, the barn can not be kept warm and it is therefore necessary to retain the heat. This is accomplished by the use of materials which do not readily transmit heat and which are adaptable to building construction.

Materials vary with respect to their conductivity or ability to transmit heat. A piece of iron with one end in the fire becomes so hot throughout its length that it can not be held in the hand. This is not the case with a piece of wood. Closely confined air divided into very small volumes so that it is without movement is a good insulator. Such air is found in the structure of wood and other insulators, the size of the small air pockets varying with the kind of material. Cork is one of the best insulators because the fiber itself is of low conductivity and because the confined air is minutely divided; but cork is too expensive for use in barn construction.

A 1-inch soft pine board, an 8-inch brick wall, and an 8-inch concrete wall transmit heat at approximately the same rate, while ordinary window glass transmits heat  $2\frac{1}{2}$  times as fast.

Thus it is evident that, generally, wood construction is less expensive than masonry so far as insulating value is concerned. If masonry is used, the thickness must be determined by the structural requirements and other materials used to secure insulation.

In cold climates frame buildings sheathed and clapboarded or shingled on the outside and sheathed or finished with lath and plaster on the inside do not afford sufficient protection from heat and cold because cracks due to shrinkage of the materials are sure to occur and through these the wind finds its way. Hence provision must be made to keep out wind and cold. There is no material so well suited to this purpose and, at the same time, so inexpensive, as good sheathing paper or felt. A good sheathing paper should have lasting quality, resistance to the passage of water, and be sufficiently strong

to bear handling without tearing. It should not be brittle and should be clean for handling.

The amount of insulation required, of course, will depend upon climatic conditions. In cold climates it may be necessary to use double sheathing with paper or felt between the layers, storm-sash, and double doors. In mild or warm climates the amount of insulation may be accordingly modified.

#### NEED FOR DIFFERENT CONSTRUCTION IN VARIOUS SECTIONS.

Changes in atmospheric conditions affect the success of a ventilation system. Figure 2 shows approximately what temperatures may be expected in the various sections of the United States. The map is based upon the average temperatures for the months of January and February over a period of 30 years at 100 selected stations and is intended to indicate the variable conditions which exist and to

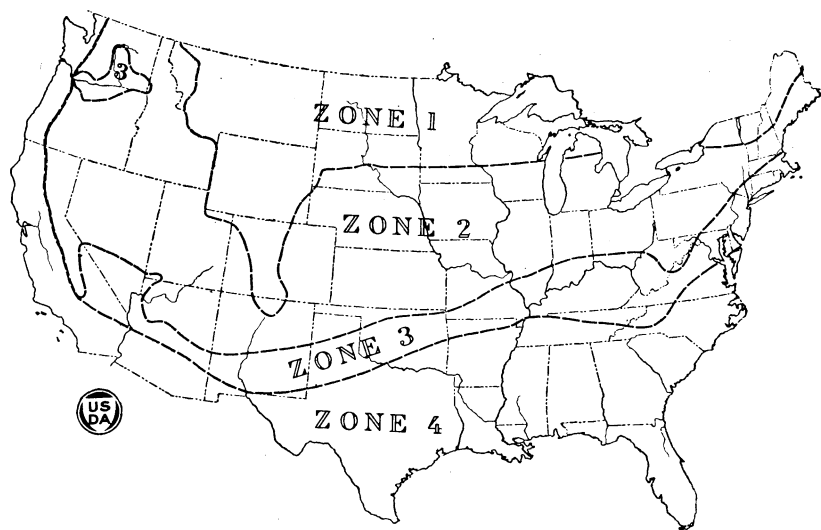


FIG. 2.—Map showing zoning of United States with respect to temperature.

show that the various zones are not by any means separated by straight east and west lines. Conditions in the northern and southern sections of the same State are often different. During mild weather the problem of ventilation is not so difficult, hence temperatures for the winter months, January and February, usually the coldest, have been used. The country is divided into four divisions or zones, according to average temperatures, and for convenience in reference the zones are numbered. In the first zone the mean monthly temperatures are below freezing from October to April and in the second zone from November to the 1st of April. In the third zone freezing temperatures occur between late November and early March, while in the fourth the mean monthly temperature is seldom below freezing.

The average of the lowest daily temperatures—that is, the daily mean minimum temperature—for the two months in the first zone is approximately 5° F., the mean monthly temperature is from

9° to 12° and the lowest temperature recorded at the selected stations is —57° F. In the second zone the daily mean minimum temperature is about 17°, the mean monthly temperature approximately 22°, and the lowest temperature recorded —43° F. In the third zone the daily mean temperature is approximately 27° F., the mean monthly temperature about 30° F., and the lowest temperature recorded —22° F. In the fourth zone the lowest recorded temperature is —11° F. This, then, is the reason why variation in the construction and method of ventilating barns in the different sections of the country is necessary.

### ANIMALS SOURCE OF HEAT.

From the discussion of the factors which control operation of a ventilation system, it is apparent that the amount of heat produced by the animals in a barn is the principal factor in securing ventilation.

Until recent years very little was known concerning the heat production of the various farm animals. It has been learned that a 1,000-pound dairy cow, kept under average conditions of feed and care, will produce approximately 3,000 heat units (known as B. t. u. or British thermal units) per hour, 1 heat unit being the amount of heat required to raise the temperature of 1 pound of water 1 degree. One British thermal unit at average barn temperature will raise the temperature of 52.8 cubic feet of air 1 degree. The heat production of various animals varies according to their size, being proportionately greater in the smaller animals than in the larger. Since the heat production of the cow has been determined, the problem of barn ventilation can be approached with a greater degree of certainty than has been possible in the past. Obviously not all of the heat produced can be saved, and the loss varies according to the construction of the barn and the climatic conditions. Hence a design suited to the climatic conditions of one section of the country may be but partially successful in another section.

A high temperature is not necessary for the comfort of the animal. Just what temperature it is desirable to maintain is open to discussion, because of the effects of many variable factors and the difficulty in tracing them in results at the milk pail. In the past it was thought that temperatures of from 60° to 65° F. were desirable, but it has been found that better results can be obtained at lower temperatures. Such high temperatures would be difficult to maintain in a barn in the colder section of the country without using artificial heat, but the lower temperatures which have been found to be satisfactory can generally be maintained without artificial heat in barns which have sufficient insulation and in which the size of the stable is properly proportioned to the number of stock housed.

The most desirable temperature of air for breathing is approximately 50° F., and this temperature may be readily obtained in barns in the central section of the country. It is suggested that a temperature between 45° and 50° F. is satisfactory for the average dairy barn in the northern section of the country.

It is sometimes desirable to provide heat in calf barns and in pen barns where the space per animal is greater than in cow barns. When artificial heat is supplied the problem of maintaining sufficient

circulation of air is greatly simplified. High temperatures may be desirable in the specialized dairy barn where high-producing cows are kept well groomed and have but a thin coat of hair, but under average farm conditions lower temperatures are more economical. The winter coat of hair on the average cow is in keeping with lower temperatures and she is apt to shed her hair if she is kept in a warm, moist stable. Then when turned out for exercise in a lot she is less able to stand the cold winter weather.

Obviously the temperature which can be maintained in a barn is dependent upon two main factors, the heat produced and the extent to which it is conserved, and these are dependent upon a number of conditions. Briefly, the maintenance of a desired temperature involves consideration of the following: Insulation, the amount being proportioned to the temperatures which may be expected in the different zones or sections; tightness of construction, to prevent excessive leakage of air; the amount of air space which the animals must heat; the amount of ventilation desired; and the method of securing it.

There are many barns in which well-designed ventilating systems are not producing satisfactory results because the buildings are too cold owing to the lack of insulation. In the northern sections storm doors and windows aid in conserving the heat within the barn and increase the efficiency of the ventilation system.

### VENTILATION SYSTEMS.

More than 40 years ago Prof. F. H. King, of the Wisconsin Agricultural Experiment Station, propounded the principles which form the basis of the method of ventilation commonly known as the "King system," the type most generally used throughout the United States. Other types are briefly described, but in order to fix in the mind the principles which govern all systems they are here applied to the King system, which has been modified in the different sections of the country in order to meet local conditions.

There are various modifications or combinations of both the King and the Rutherford systems often supplemented by the use of ventilating windows or canvas curtains. In all of these, inlet flues are used to bring in fresh air and outtake flues to remove foul air and odors. The flue systems are undoubtedly the most efficient as they permit of the uniform distribution of air and control of the amount of ventilation and of the stable temperature.

#### KING SYSTEM.

The King system of ventilation provides for a number of small intakes and one or more large outtakes. Fresh air enters above the sills, rises between the studding, and enters the stable at the ceiling. The outtake flues start near the floor, passing upward inside the barn, through the mow to the ventilator on the roof. The total area of the intakes is generally made two-thirds of or equal to that of the outtakes, depending upon climatic conditions (see figs. 3 and 4). There are no accurate data with respect to the actual velocity of air in flues of different heights. Using King's recommendation as to the amount of ventilation required and assuming a flue velocity of 250 feet per minute, which is approximately that which may be ob

tained in a 30-foot flue under average conditions, the flue areas given in Table 1 have been computed. The flue velocity will vary according to differences in temperature and height of flue.

TABLE 1.—Air breathed, air required for ventilation, and size of outtake flues per head.

Animal.	Breathed per hour.	Required for ventilation per minute.	Area of outtake flue.
	<i>Cubic feet.</i>	<i>Cubic feet.</i>	<i>Square inches.</i>
Horse.....	142	70	40
Cow.....	116	59	34
Pig.....	46	23	13
Sheep.....	30	15	9

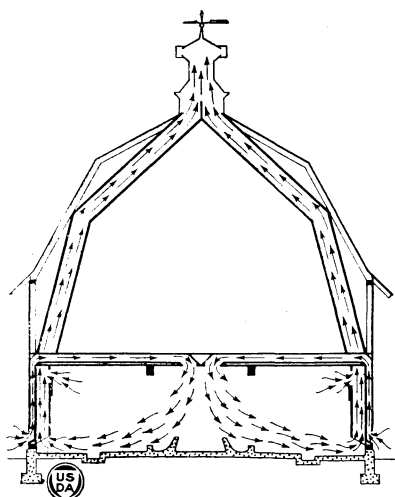


FIG. 3.—King system of ventilation. Cows facing inward.

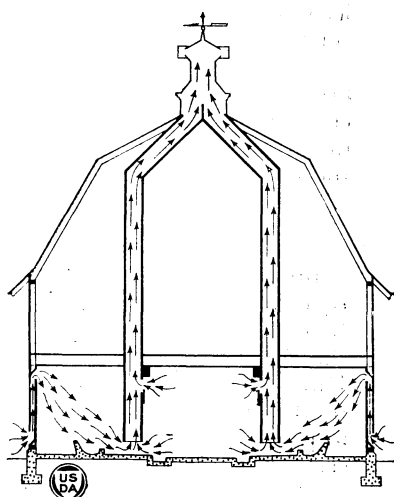


FIG. 4.—King system of ventilation. Cows facing outward.

#### RUTHERFORD SYSTEM.

In the Rutherford system (see fig. 5), commonly used in Canada, the positions of the air inlets and outtakes are just the reverse of those in the King system. The fresh air enters the inlet flues a little above the floor level, turns downward, passes inside, and rises in the stable. The outlet flues start at the ceiling, pass up through the mow, and terminate at the ventilator. In this system the total area of the outtakes is made twice that of the inlets.

The outtake flue area per animal recommended by King is much greater than that used in the Rutherford system, which means that height of outtakes, weather, and other conditions being equal, proportionately greater ventilation will be obtained with the King than with the Rutherford system.

The reason for this difference is that the Rutherford system is based on weather conditions existing in Canada, while Professor King's recommendations are for a milder climate where there is less wind.

Recent investigations indicate that it is necessary to decrease the size of the outtake flues of the King system when used in cold sections of the country.

#### MODIFIED KING SYSTEM.

A modification of the Rutherford and King systems (see fig. 6) retains the inlets of the King system but removes the foul air through flues starting at the ceiling, as in the Rutherford system. The relation between the sizes of outtake and intake flues is similar to that of the Rutherford system in order to compensate for differences in climatic conditions and the position of the outtake openings. This system can be successfully used if it be designed carefully with respect to local conditions and if it is properly operated.

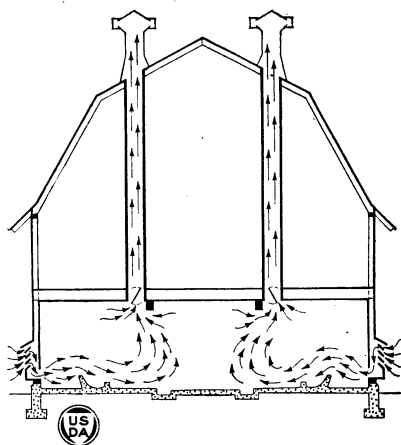


FIG. 5.—Rutherford system of ventilation.

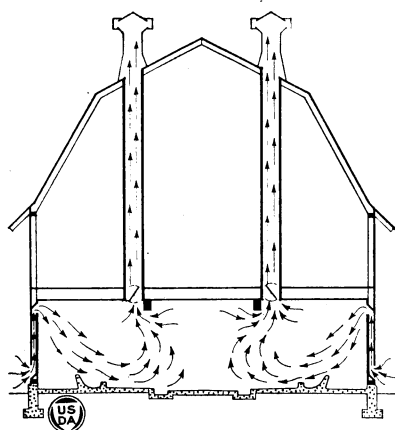


FIG. 6.—Modified King system of ventilation.

#### WINDOW VENTILATION.

In many barns the only ventilation to be had is by means of open windows. Some windows are double hung; that is, they have two sashes, opening and closing as the ordinary house windows. Others open by sliding, while still others tilt in at the top and are provided with shields on each side which force the air to go over the top and mix with the warm air at the ceiling (see fig. 7). Although it is true that some ventilation may be obtained in this manner, the use of window intakes does not admit of uniform regulation of the ventilation. If the windows are fitted loosely there is a considerable leakage around the openings. If fitted tightly the sash may absorb moisture, swell and stick in the frame, thus interfering with their use, and if they are forced open the glass often is broken.

The limitations of ventilation secured through window intakes in cold climates are clearly shown by data secured in recent tests. That these limitations are not widely known is made evident by the frequent use of such intakes in unsuitable places. It is not the intention to imply that ventilation through window openings is impossible nor to advise against their use in mild weather or in southern

zones. They are useful as a supplement to the ventilating system in mild weather. They can be used when the outside temperature is above freezing and when the circulation of a large quantity of air does not cause harmful drafts on the animals, but their use should be restricted during cold weather when it is obviously impossible to supply large quantities of cold air without chilling the animals near the windows.

In cold climates it is especially desirable to ventilate by means of wall-intake ducts. The window sash can then be closely fitted and storm sash provided, thereby preventing undue lowering of stable temperature without restricting the amount of ventilation. Storm sash retard and in most cases prevent the formation of frost on the glass. The purpose of windows is to admit light into the barn, and if covered with heavy frost their usefulness is greatly diminished. If the windows are used as intakes the formation of frost can not be avoided in cold weather, and if the temperature is not quite low enough to form frost moisture condenses on the panes, runs down the sash, rusts the bottom hinges, and rots the sills and frames. The most serious objection to windows as intakes in cold sections, and the reason that no reliance can be placed upon window ventilation, is that it is difficult to control the temperature and the amount of ventilation, because of the variation in the direction of the wind, which makes frequent adjustment of the windows necessary.

Ventilation through muslin curtain windows has been tried with little success. The movement of air through the very small meshes of a good grade of muslin is very slight. Cheesecloth, or other material having more open meshes, is short lived. The cloth becomes damp, moldy, and dirty, and soon rots out.

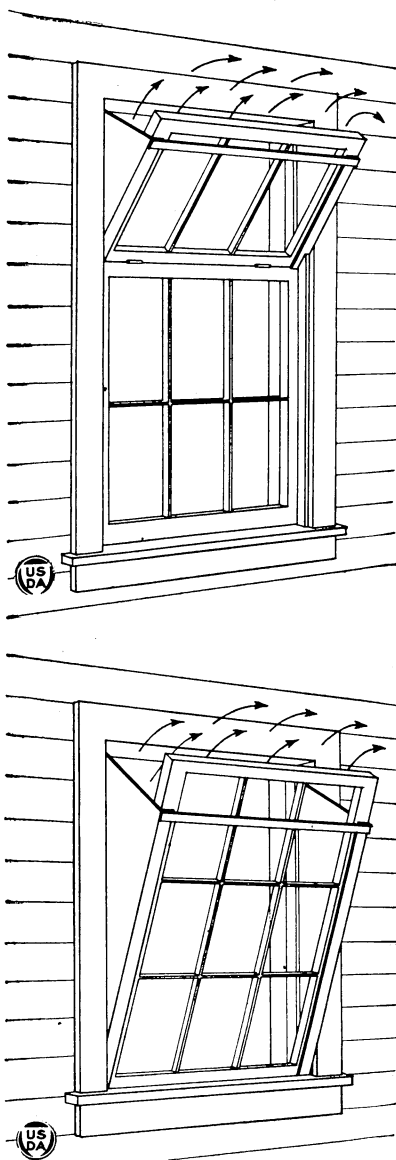


FIG. 7.—Two methods of arranging windows for ventilation.

**CRACK SYSTEM.**

Cracks and crevices in the walls and around openings interfere with the regulation of the ventilating system. There is in all cases some leakage of air at points other than the openings provided for in the ventilation system. The amount varies according to the tightness of construction and the difference between inside and outside temperatures. Although this leakage aids in the dilution of the stable air, it is not desirable in large volume because there can be no regulation of the temperature and variations in the outside temperature cause similar variations in the inside temperature.

This is the objection to the "crack" system of ventilation which is sometimes found in old barns (fig. 8). In well-built modern barns leakage is greatly reduced and the efficiency of the ventilation system increased. Nevertheless there is always some leakage and it is greatest at times of high wind velocity and low temperature.



FIG. 8.—"Crack system" of ventilation. No light, little sanitation, and too much ventilation.

**CONSTRUCTION.****TYPE OF BARN.**

It has been found very difficult to ventilate some one-story barns because of their high ceilings and the excessive loss of heat through the ceiling where it is not properly insulated. If the ceilings are high the air space per animal, as determined by dividing the total cubic contents by the number of stock, may be so large that the body heat of the animals will not be sufficient to heat the stable, and condensation of moisture on the ceiling may occur.

In the northern zone or those sections where conservation of heat is necessary, not much over 600 cubic feet of air space per animal should be permitted and the allowance should never exceed 800 cubic feet. A large volume of space is not essential to purity of air, as without circulation the air may become just as badly polluted as in a more confined space. The essential of good ventilation is the circulation of the air.

The haymow of the two-story barn aids materially in the conservation of heat, as the hay retards the loss of heat through the ceiling. The two-story barn permits of high outtake flues which are desirable because of the greater draft. The ceiling joists should be ceiled on

the underside. If it be properly built no objection can be raised to this type of barn from the standpoint of clean milk production. In building bank barns, which are not recommended for dairy purposes, special care should be taken to provide for a uniform circulation of air throughout the stable. In this type of barn windows are usually lacking on the bank side, making it difficult to secure proper ventilation and sufficient lighting.

#### WINDOWS.

Glass surfaces radiate heat rapidly, hence when conservation of heat is important it is necessary to give careful consideration to the window spacing. Sunlight is nature's disinfectant and too much of it can not be had in the barn during the winter, but too many windows means greater loss of heat through the glass and leakage of air around the frames tending to keep the barn cold. Windows should be installed with the long dimension vertical, as this will permit the entrance of the sun's rays for a longer period during the day.

Four square feet of glass area per animal is desirable. In the warmer zones a greater area can be used to advantage, while in a few cases in some of the colder sections slightly less area would render it easier to maintain a desirable stable temperature. The distribution of the windows is of greater importance than the area of glass. Instances have been observed in which barns having but  $3\frac{1}{2}$  square feet of glass per cow were better lighted than others in which the glass area was 6 feet per cow but unevenly distributed. Windows should be evenly distributed so as to permit light to reach all corners of the stable. From the standpoint of sanitation it is not possible to provide too much light, but because of the rapid radiation of heat from glass it is necessary to make the area compatible with local climatic conditions.

#### HAY CHUTES.

Open hay chutes interfere with ventilation and should not be used as foul air shafts. In one barn visited by the author metal cupolas were installed in the roof, but no special ventilating flues were provided, the hay chutes being used to conduct the foul stable air to the ventilator. Although the outside temperature was from  $10^{\circ}$  to  $12^{\circ}$  F., the roof sheathing was found to be dripping with moisture. Such a condition is not conducive to long life of roof timbers. The dropping of condensed moisture spoils the hay and may cause fires through spontaneous combustion. It is obvious that the bottom of hay chutes can not be left open if the foul air flues are to perform their function properly. Air seeks the easiest passage, and a large opening in the mow floor provides a quick exit from the stable below. Hay-chute openings should be closed by means of hinged or sliding doors so arranged that they may be easily operated.

#### VENTILATORS.

The purpose of roof ventilators, or ventilator heads, is to aid in the displacement of the air within the stable and to provide protection against storm. The old wooden cupola with its slatted louvers

is now regarded as obsolete (see fig. 9). The louvers retard the passage of air and, when the wind is strong, air currents are set up within the cupola, often killing the draft within the flue and causing backdrafting. Wooden cupolas without slats are more efficient, but do not afford storm protection. Properly proportioned and well designed metal ventilators are more efficient and provide greater protection against snow and rain. The throat opening should be large enough to permit the free passage of air and at the same time it should be so designed as to prevent wind blowing down the flue. The successful ventilator is more than a few pieces of sheet metal. Not every tinsmith knows the correct dimensions and the relation that the several pieces should bear to each other. Hence home-made ventilators are apt to be inefficient if not complete failures.

#### OUTTAKES.

Outtakes are usually arranged in pairs. When the cows are to face inward (fig. 3) the outtakes are placed on the outside wall on each side of the barn and often enter the same ventilator at the



FIG. 9.—Old-style wood cupolas. Inefficient as ventilators, too often monstrosities and places for birds' nests.

ridge. The flue should be made air-tight and as straight as possible, with no abrupt turns. Horizontal flues should not be used, as they greatly decrease the efficiency of the flue. A large number of small outtake flues is not desirable, particularly in the colder sections, because in passing through them the air becomes chilled more rapidly than in flues of large area. More even distribution of the air is obtained by using a smaller number of outtake flues of larger area. In barns less than 60 feet in length, the equipment generally consists of one ventilator with one or two pairs of flues. A barn 60 to 80 feet long usually should have two ventilators; in longer barns the number of outtakes is increased proportionately. However, the exact number of outtakes is dependent upon the number and arrangement of the stock in the barn.

Several different arrangements of outtake flues are used. Some pass directly out through the roof at the plate; others, if the roof is of the gambrel type, continue along the lower set of rafters and pass out at the break; the most common practice is to continue them to the ridge of the roof (see fig. 3). In the first method it is necessary that that part of the flue above the roof be extended to above the level of the ridge and double insulated, otherwise the ad-

vantage of a straight flue will be nullified by the quicker cooling of the air within. If the air in the flue is allowed to become too cool it will tend to drop and will cause condensation and back action in the flue. The second method is more often used where stock is housed on one side of the barn but the mistake is often made of not extending the ventilator to a sufficient height. The level of the ventilator top should be well above the ridge or the highest part of the roof (see fig. 5). The third method is generally used because it requires a small number of ventilators and the appearance of the barn is improved.

It is essential that the flues be well insulated and air-tight in order to prevent, so far as possible, the cooling of the air during its passage and the condensation which will take place regardless of the material used in the construction of the flue (see fig. 10). If the flues are constructed of wood they should be double-boarded with matched lumber and with a good grade of building paper or roofing

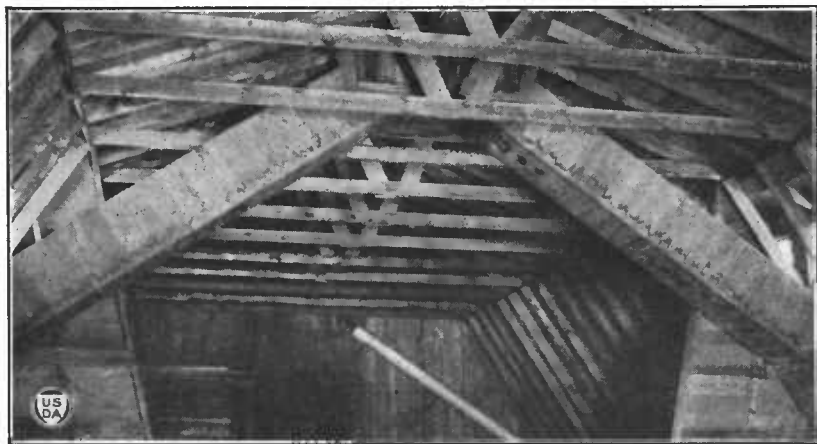


FIG. 10.—View showing installation of wood flues. Note incipient rot caused by condensation of moisture.

felt between the two layers. A single layer of matched lumber is not sufficient for that part of the flue above the mow floor.

The author recently visited a new barn, which cost \$12,000 or more, in which a single thickness of boards was used in constructing the outtake flues. Excessive condensation will result and, during severe weather, frost. The boards, having absorbed moisture, will dry out during the summer months, leaving cracks which will reduce the draft within the flues and may even nullify it. In another barn the outtake flues had so many cracks and holes that no circulation of air was obtained through them except during periods of high wind velocity. Another instance of poor construction was that of a barn in which the outside sheathing of the roof and side walls formed one side of the outtake flue. Frost and ice had formed on the roof and side walls, peeling the paint from the outer surface.

In the better installations of ventilation systems, round metal flues (see fig. 11) are now being used. A round flue is more efficient than one of square or rectangular shape and of the same cross-

sectional area and for this reason a smaller flue may be used. Bare metal pipes are unsatisfactory and require insulation, as do wooden flues. Metal flues may often be erected with much less labor than wooden flues and in many localities can be installed more cheaply.

The outtake flues are controlled by means of dampers which should be so arranged that one may readily see whether they are open or closed. In the King system, openings often called "heat doors" are made in the outtakes near the ceiling to permit the rapid removal of warm air from the upper part of the stable during mild weather. The heat door openings should be of approximately the same area as that of the flue.

#### INTAKES.

The intakes should be smaller in size than the outtakes and of greater number. They are generally placed 10 or 12 feet apart and so distributed as to insure a good circulation of air in all parts



FIG. 11.—An installation of well-insulated metal flues.

of the stable. In the King system, intakes start above the sill, rise between the studding, and discharge into the stable at the ceiling. The total area of intake openings is usually two-thirds of or equal to the area of the outtakes. In the colder sections it should be less, but air will enter the stable as fast as the outtakes remove it, and if the intake area is too small the velocity of the incoming air will be so great as to cause drafts.

Intake flues should be made air-tight. If the barn wall is not double sheathed, at least the outside wall of the intake flue should be, as the cracks in a single layer of sheathing will affect the efficiency of the flue. The inside wall of the flue should be insulated, otherwise cold air passing through the duct cools the inner surface of the stable wall, causing condensation and consequent dripping. During cold weather the path of uninsulated intake flues often is indicated by the frost on the walls and ceiling.

It is natural to expect that the velocity of the air will be greater through intakes most exposed to the wind. In a series of tests the

velocity of the air through the windward intakes at times was found to be four times that on the leeward side. As the wind increases the velocity of the air coming in on the leeward side gradually decreases and, if the wind is high enough, back drafting may occur. Back drafting is common in leeward intakes near corners or where milk houses, silos, or other nearby buildings deflect the currents of air. In planning the ventilation of a barn the placing of intakes at the corners should be avoided. When whirls are formed by deflected currents the air sometimes goes in and sometimes out of one or more intakes and this reversal may take place in less than half a minute. The effect of wind at the corner of a building is shown in Figure 12. It is evident that at the corner inlet, which is on the leeward side, a suctional effect may be set up, causing back drafting.

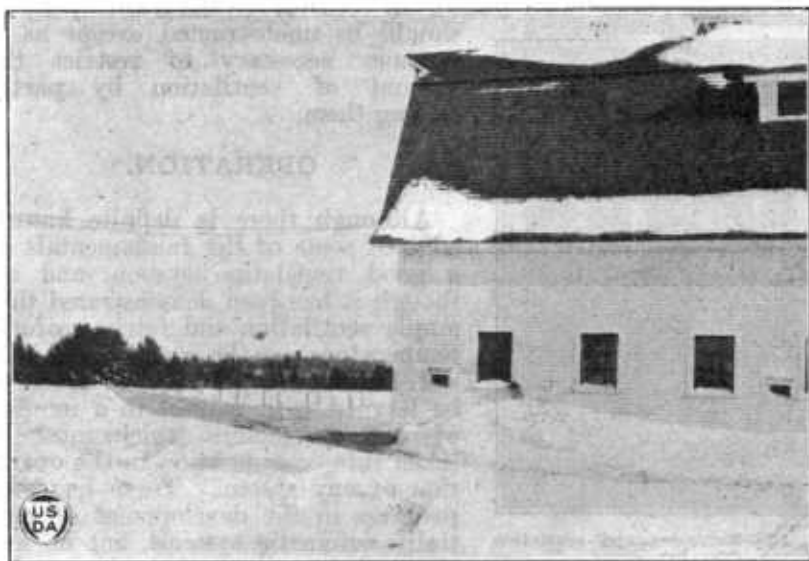


FIG. 12.—Effect of wind currents at corner of a building.

The tendency to back draft is minimized in an inlet placed 8 feet or more from the corner of the building.

Back drafting and the velocity at which it occurs is often due to the design, as well as the position of the intakes. In recent tests the lowest wind velocity producing back drafting in wall intakes 5 feet or more in length was 6 miles per hour, but back drafting in window intakes was not uncommon with a wind velocity of 3 miles per hour and in one instance occurred when the wind velocity was less than 1 mile per hour.

The outside openings of intake flues should be at least 5 feet below the inside openings in order that the warm stable air shall be trapped at the ceiling and not pass out through the intakes. Figure 13 shows how in one instance the vertical height of intakes flues was increased. The additional length lessened the back drafting but did not prevent it when the wind reached a velocity of 16 miles. Automatic intake valves, which are designed to prevent back action,

have recently been placed on the market. When these valves are used the vertical part of the flue is omitted. It is necessary that they be set level and plumb, as otherwise undue friction might impair their action.

#### INLET OPENINGS.

Warm-air furnace registers should never be used in the openings of outtake or intake flues. The slats rust, break, and collect dirt and cobwebs, and during cold weather registers on intakes collect frost to an extent that sometimes renders the entire area ineffective. The grates and shutters retard the passage of air. A board, either hinged or sliding in a slot, is preferable to the furnace register as a means of regulating the area of the openings. It is necessary to screen the outer openings of the inlet ducts to prevent entrance of trash and vermin, but the passage of air through the inner openings should be unobstructed except as it becomes necessary to restrict the amount of ventilation by partly closing them.

#### OPERATION.

Although there is definite knowledge of some of the fundamentals of a good ventilation system, and although it has been demonstrated that ample ventilation and fairly uniform temperature can be maintained in a well-built barn, yet there is much to be learned with respect to a number of variable factors which must be taken into consideration in the operation of any system. There has been progress in the development of partially automatic systems, but no mechanical device can make it possible



Fig. 13.—Extension and protection of intake opening.

to dispense entirely with personal attention and the exercise of judgment which can be acquired only through experience. It is not possible to lay down a set of directions applying to all ventilating systems, or to all the conditions which are encountered in any one barn. The object of this bulletin is to explain the principles of ventilation as applied to barns, to set forth certain facts that are definitely known, and to offer suggestions that will assist farmers in acquiring the experience and judgment necessary to successful operation of a gravity system of barn ventilation.

If the ventilating system has been installed by a commercial firm, the owner should obtain a set of directions, go over it in detail with the firm's representative, and have the construction and operation thoroughly explained, so that when he undertakes the operation himself he will be better able to adjust the system to varying atmospheric conditions.

As explained in the foregoing pages, the barn must be made tight and provided with intake and outtake flues, the openings of which must be adjustable. The walls of the stable, and particularly the

intake and outtake flues, must be well insulated if dampness within the stable is to be avoided. In the colder sections the windows should be fitted with storm sash and entrances should be provided with storm doors. Properly designed ventilator heads should be provided at the top of the outtake flues. The barn must be kept clean, for, although ventilation will reduce or displace foul air, freshness of atmosphere can not be maintained if manure and foul-smelling débris remain in the stable. The barn should be filled with stock, or unoccupied portions should be filled with hay or straw or cut off with a temporary partition. The heat generated by the stock is the means by which a difference between inside and outside temperatures is brought about, thus causing circulation of the barn air, and if the space is too large for the number of stock there may not be sufficient heat generated to maintain the desired temperature and at the same time produce ample air circulation.

In determining the conditions prevailing at any time within the barn the farmer must depend for the most part upon observation and the sense of smell. A number of thermometers, depending upon the size of the stable, should be placed at various points at a height of about 5 feet, and where incoming air will not blow directly upon them. By reading the instruments at regular intervals—say, two or three times a day, or when marked changes occur in wind velocity or direction or in the outside temperature—the tendency of the stable temperature to rise or fall will be known and an adjustment of the system can be made accordingly. At least one thermometer is necessary in order to determine the temperature, but a larger number will be found more desirable.

High temperature is not necessary to comfort, 45° F. being satisfactory for the average dairy barn. One should not guess at the temperature, especially in cold weather, since upon entering the barn it may seem much higher than it really is because of the contrast with the low outside temperature. Nor can the temperature of the barn be judged by feeling the air at the intakes, for although the incoming air may be quite cold it becomes diffused with the warmer air of the stable.

The degree of temperature that will be comfortable to the stock will depend upon the relative humidity or moisture content of the stable air. Just what the relative humidity should be has not been determined, but there is little danger of its being too low. The farmer must rely upon observation to determine whether too much moisture is present. If, when the inside temperature is about 45° F., the walls and ceilings are dry and there is an appreciable circulation of moderately dry air, the condition within the stable generally may be considered good.

It will not be feasible for the average farmer to determine the amount of ventilation—that is, the number of times the air in the stable is changed within an hour—but he can learn to judge it fairly well. The air should be fresh and clean to the smell; there should be no pronounced drafts over any of the stock; there should be appreciable movement of air inward at the intakes and upward through the outtakes. Back drafting, or outward movement at the intakes, is indicated in cold weather by the melting of any frost that may have previously formed around the opening. The direction of the

air movement may also be determined by holding a moistened finger in front of an opening. The direction of the air current will be toward the side of the finger which feels cold; a handkerchief or cloth or a piece of paper held at an opening will also indicate the direction of any pronounced movement.

In mild weather it may be that the temperature in the stable will become too high and that there may be too little circulation of air. If the outtake flues extend to the floor and are fitted with heat doors the latter should be opened.

Assuming the conditions within the barn to be normal, or good, as described above, a decrease in outside temperature will, ordinarily, cause more rapid movement of air into and out of the barn and a consequent lowering of inside temperature. To correct this the area of each intake opening should be gradually reduced. Should the drop in outside temperature be accompanied by high wind a greater reduction of intake area will be necessary. As soon as the weather conditions moderate the intakes should again be opened, the idea being to maintain as great a circulation of air as possible with the inside temperature at the desired degree.

Generally any intakes found to be back drafting should be closed, especially during periods of low outside temperature. Should the inside temperature not then remain normal it may be advisable to close partially all intakes on the windward side, thus relieving pressure on the inside.

A high temperature within the barn should not be maintained at the expense of wet walls. Should the humidity become noticeable the barn may be dried out by increasing the circulation; that is, by opening the system.

Should a portion of a large stable be temporarily unoccupied it would be well to close the outtake flue entirely in that part. This will reduce the circulation and aid in maintaining the stable temperature. The partial closing of an outtake reduces the velocity of the air in the flue, the result being too rapid cooling and consequent condensation and dripping.

Damp walls can not be avoided if there is insufficient insulation. Lack of insulation is indicated by the presence of dampness when the atmosphere within the stable is above the saturation or dew point.

The success of a ventilation system depends upon the correct application of those principles which control the condition of the air. The principles themselves can be readily understood, but their application is still so largely a matter of judgment and experience that it is not possible for every farmer to be his own ventilation engineer. Farmers will therefore save much time and money if they will submit their ventilation problems to their State agricultural college, the United States Department of Agriculture, competent agricultural engineers, or to those commercial firms which specialize in the ventilation of farm buildings and which obtain results that show them to be using the best information available. The next few years will see a rapid advance in the use of properly installed ventilation systems designed to meet local conditions.